HERO: High-Energy Replicated Optics

HERO Program

- **HERO, for High Energy Replicated Optics is an evolutionary balloon program.**

- **Utilizes in-house-fabricated hard-x-ray mirrors *plus* supporting x-ray detectors, gondola and pointing system.**

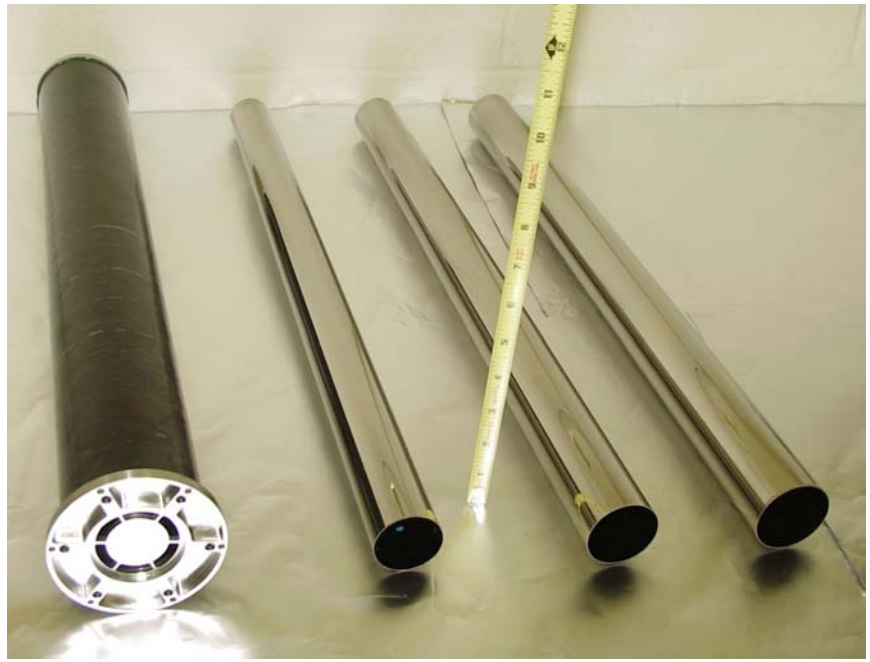
- **Optic design philosophy :**
  - Utilize a large number of shallow-graze-angle, iridium-coated full-shell mirrors
  - Obtain significant collecting area by using narrow-aspect ratio mirror shells (ie large length to diameter ratio), by nesting many thin shells and by using multiple mirror modules.

- **Mirrors are made via an electroformed-nickel-replication process. Thin shells are electrodeposited onto a super-polished and figured master (mandrel) from which they are later released by cooling.**
  - Permits multiple high-quality copies to be made from a single master.
  - Provides high-angular-resolution optics

Mirror Shell Production

Current Flight Configuration

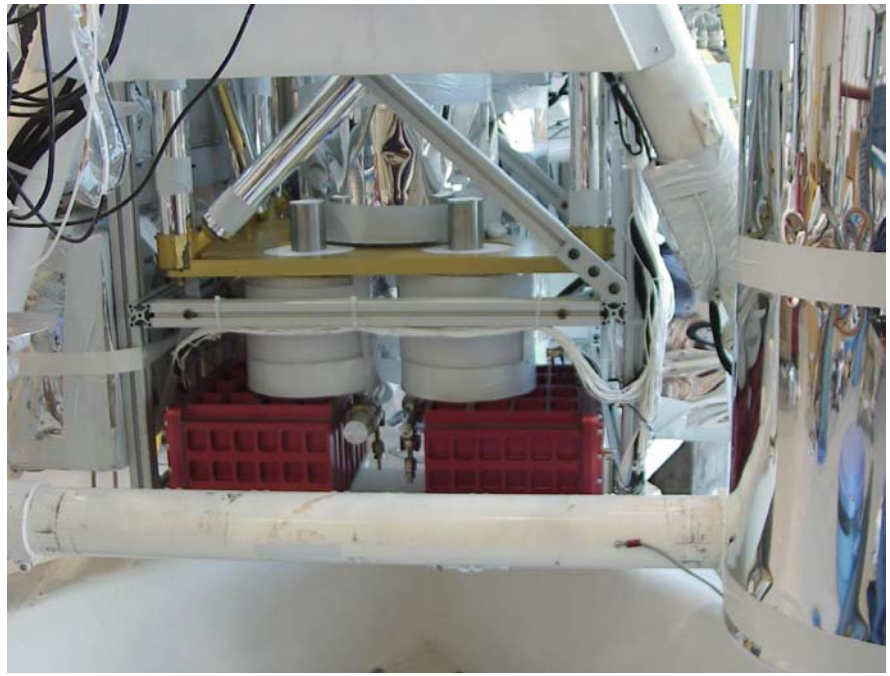
- **Two mirror modules**
  - Each module has 3 nested shells
  - 40, 44, and 48 mm diameter
  - 3 meter focal length
  - 2 cm^2 collecting area each
  - 45 arcsec module HPD
  - Energy cutoff = 50 keV
  - FOV (30 keV) = 9 arcmin diam (50%)



- **Mirror Shells**
  - 61 cm long
  - 0.25 mm thick glassy nickel alloy
  - Iridium coated
  - Half Power Diameter (HPD) of 30 arcsec

Current Flight Configuration

- **Detectors:** ***Imaging Gas Scintillation Proportional Counters***



Sensitive Area: Approximately 20 cm^2

Fill Gas: 50 mm of Xenon + Helium (96/4) at 10^6 Pa

Entrance Window: 3.2 mm Beryllium

Light Emitting Region: 4.0 mm deep

Exit Window: 7.0 mm of Suprasil

Phototube: Hammamatsu 4268, position sensitive, quartz window

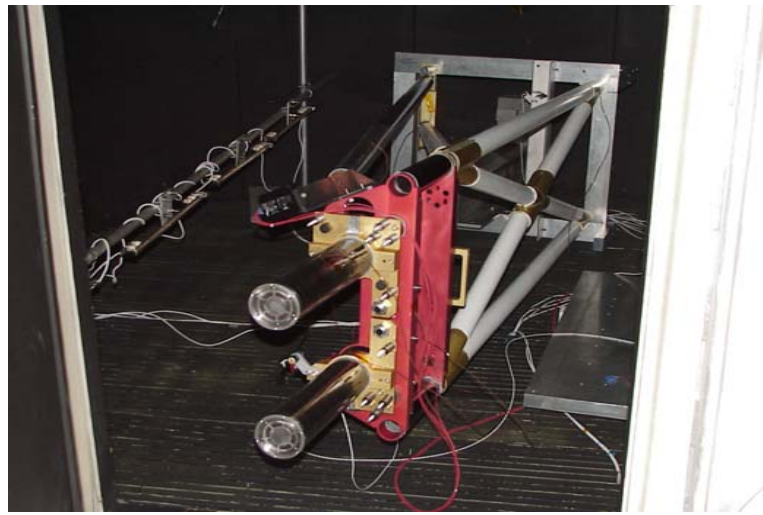
Quantum Efficiency: 99% @ 40 keV, 89% @ 60 keV

Energy Resolution (FWHM): 5% (30 keV), 4% (60 keV)

Position Resolution (FWHM): 420μm (15-25keV); 330μm (25-35 keV); 400 μm (35-45 keV)

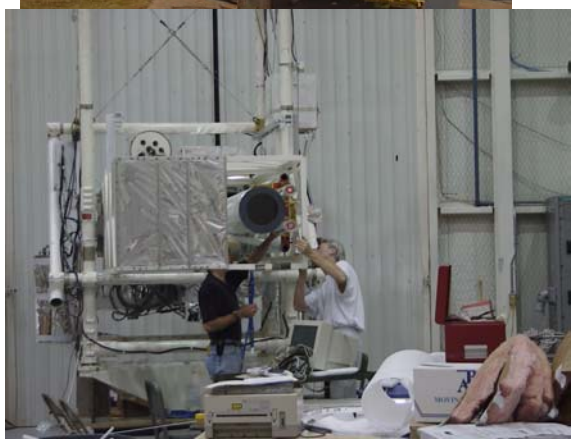
Current Flight Configuration

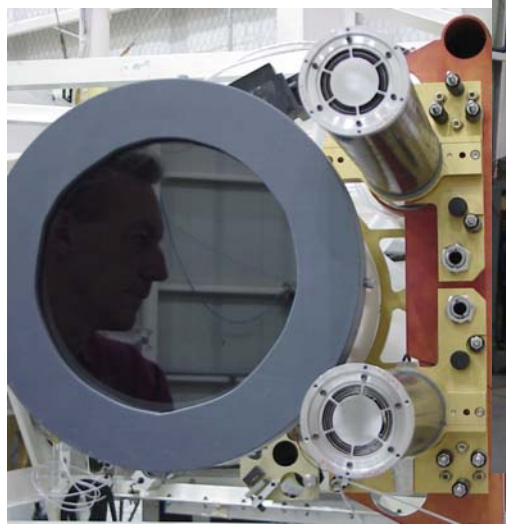
- **Optical Bench**
  - Carbon fiber with individual tip/tilt mount for each mirror module
  - In-flight laser alignment monitoring system



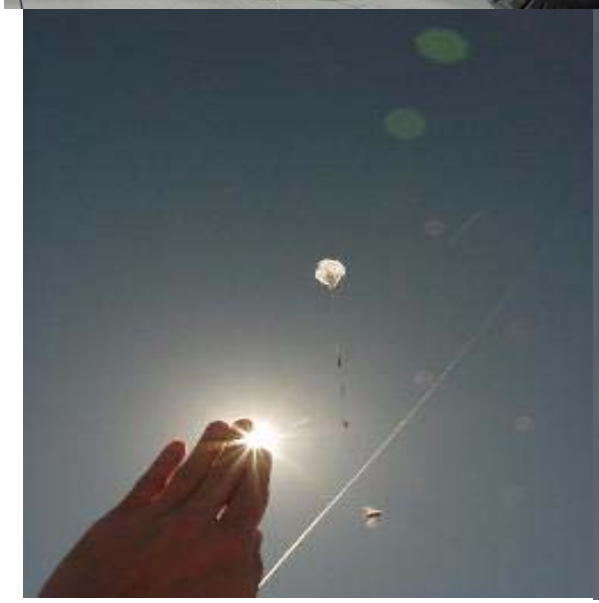
- **Gondola**
  - Alt/Azimuth mount for optical bench
  - Coarse pointing system based on global positioning system
  - Fine inertial system based on gyroscopes updated from a day/night star camera
  - Autonomous operation from on-board star catalogs

Gondola Assembly

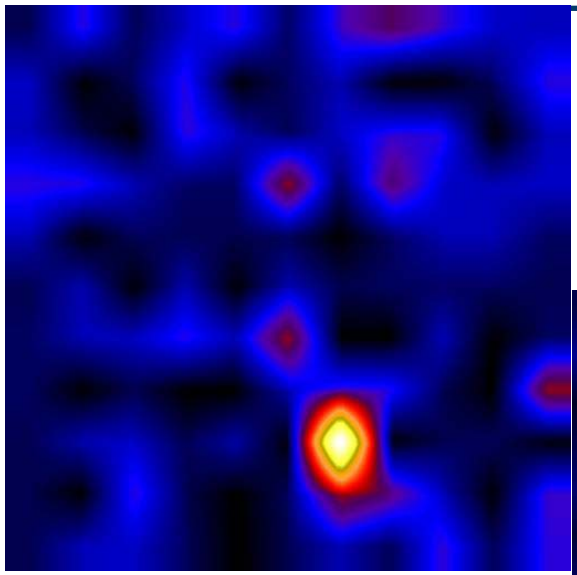




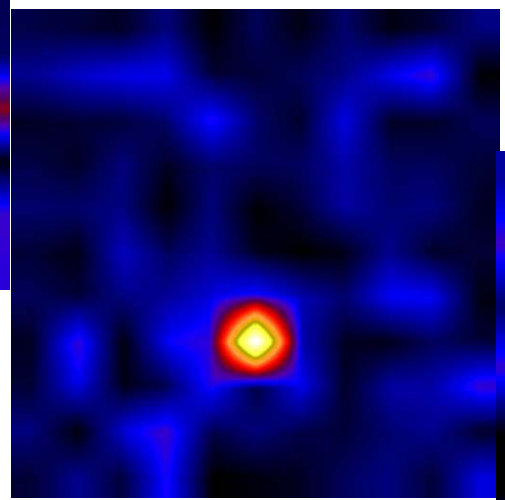
The Launch



Images

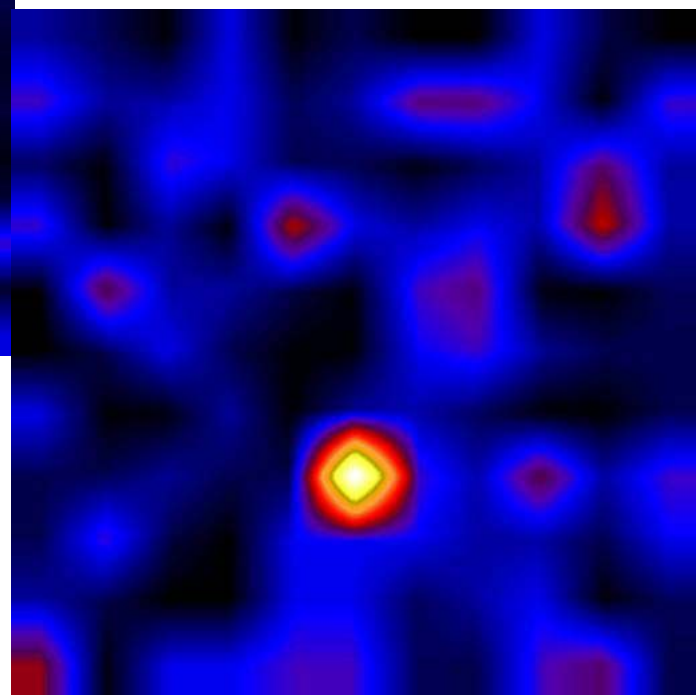


Crab



Cygnus X-1

GRS 1915



Flight Performance

- **Payload launched on 23 May, 2001, from Fort Sumner New Mexico**

  - ~ 17 hours at float
  - 39km altitude day, 37 km night
  - All systems worked well

  - Gondola held pointing to < 30 arcsec (33% of time), 60 arcsec (60%)
  - Aspect derived to 8 arcsec day and night for image reconstruction

  - Cyg X-1, Crab and GRS1915 seen at 8σ ,8σ and 6σ over 20-45 keV
  - ***First hard-x-ray focused images***

Future Plans

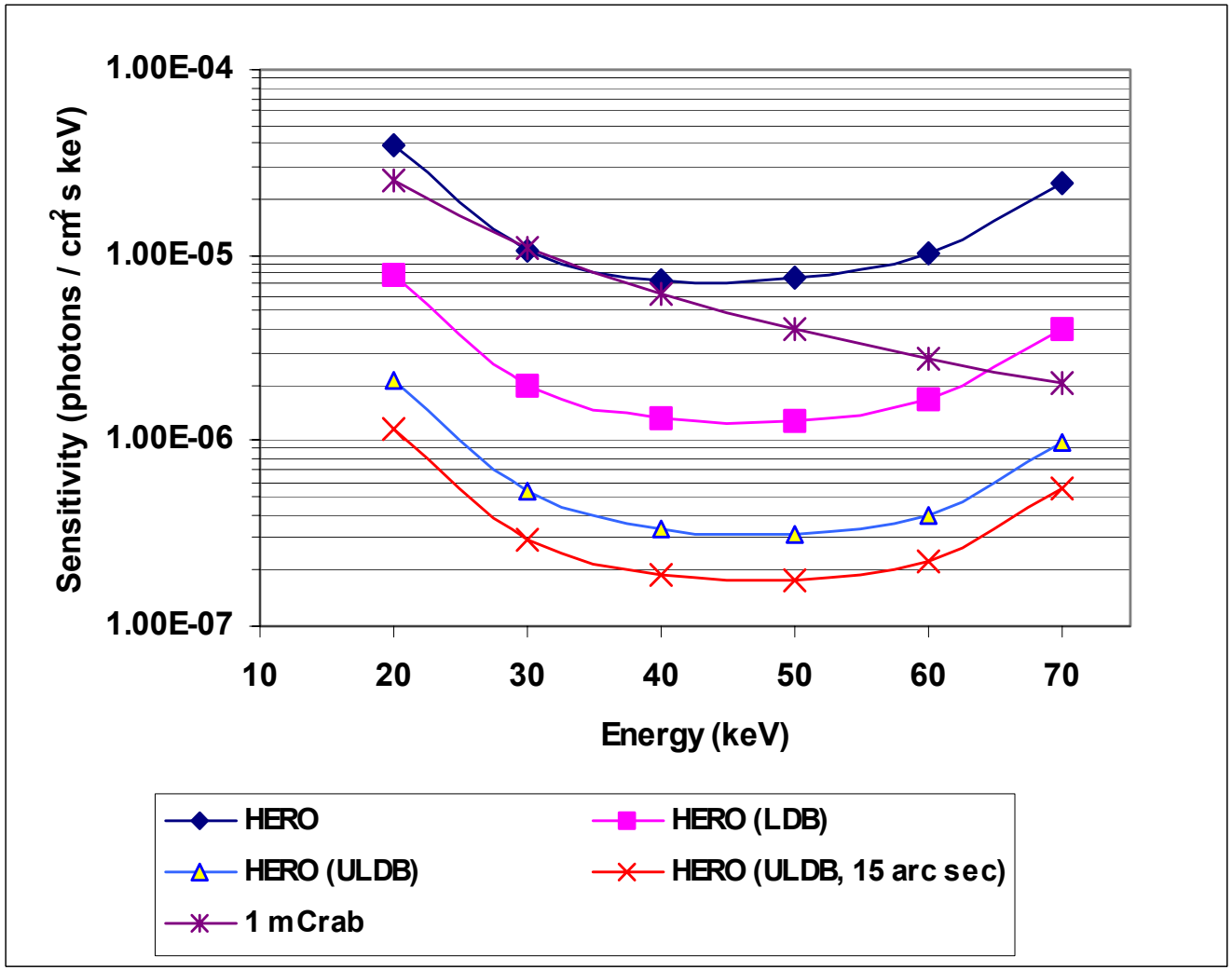
- **Modify Gondola for 6-m focal length optics**
  - Longer focal length will give greater collecting area and improved high-energy response
- **Increase module size**
  - 15 shells ranging from 50 to 95 mm diameter
  - 12 mandrels already in production (first [94 mm] ..metrology gave HPD 10 arcsec core)
  - Effective area 12.5 cm^2 (40 keV) 7.5 cm^2 (60 keV)
- **Improve angular resolution**
  - 30 arcsec HPD (already demonstrated up to 60 keV)
  - 10 – 15 arcsec HPD goal
- **Increase number of modules**
  - 8 by 2003
  - 16 by 2004 – 200 cm^2 at 40 keV. …this will give a sensitivity 1000 times greater HEAO-3 survey
- **Investigate adding extra outer shells with multilayer coatings**
  - Extend energy range beyond Iridium K edge (76 keV)

New High-Resolution 6-m-Focal Length Mirror Shells

- **New mirror shells from 10 arcsec mandrels**

- Above shows new outer HERO shell (94mm) alongside spring flight module.
- Uncoated shell was recently measured to have 16 arcsec HPD (20 keV) with simple support.

5-σ Sensitivities (16 Mirror Modules)



Application to Con-X HXT

- Some developments of relevance to HXT :
  - Low cost mandrel production (<10k / mandrel)
  - High strength alloys permit very thin shells
  - Release under water/alcohol provides low-stress separation of thin shells
    - *High angular resolution demonstrated*

- To meet the (original) weight budget of HXT requires shells ranging from 12 cm to 40 cm diameter, and thickness from 0.1mm to 0.15 mm.
  - HERO shells are 0.25 mm thick, 9.4 cm diameter (outer)
    - *But 50 cm diameter, 0.15-mm-thick shells have also been fabricated*

- MSFC will provide replicated shells to SAO for multilayer coatings. These will then be tested at MSFC .

Large-Mirror-Shell Development

- Figure at right shows a 0.15 mm thick, 50 cm diameter shell on the metrology station.
- Metrology of figure predicted a geometric core of 38 arcsec HPD
- After stress relief this improved to 19 arcsec HPD.